Learning Visual Illusions as an Approach to Overcoming Child's Misconception about Mass and Shape

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(Received August 12, 2020; Accepted September 10, 2021)

Many elementary students have a well-known misconception that when the shape of an object changes, its weight also changes. To overcome this misconception, students need to rethink critically on their sensory judgments about shape and weight. In this viewpoint, examples of the visual illusions were introduced to let students be interested in their restriction of visual recognition. In this study, we hypothesized that discussions on the visual illusion are effective for elementary students to understand the volume and weight of objects correctly. Pre- and post-class tests showed that the students in the class who experienced the visual illusions and discussed them made significant improvements in overcoming misconception about the weight of the object.
Key words: Critical Thinking, Misconception on Weight, Visual Illusion, Science Education

1. Introduction

1.1 Overcoming misconceptions from optical illusion learning

In a field of elementary school science, "the weight of object," a misconception is known to occur commonly. That is, many students take it natural that the weight changes as the shape of an object changes (Kudo, 2011). In a survey of Japanese fifth graders, many students answered, "the weight changes before and after the sugar melts." These indicate a difficulty in understanding the fact that the weight of objects does not change even if they dissolve in water (National Institute for Educational Policy Research, 2012).

Pine, Messer, and John (2001) suggested that misconceptions originate from concepts that children have established in some way in their daily lives. Regarding misconceptions, Magara (1996) stated that learners learn various things from daily life even before they receive a systematic education. As for the difficulty of correcting misconceptions, Kuhn (1989) showed that misconceptions are powerful and resistant to education.

Pine, Messer, and John (2001) argue that children hold many incorrect ideas about the science topics in the primary curriculum, and these incorrect ideas should not be ignored, since they are the foundations upon which new knowledge is built. Also, they suggested that remembering children's false beliefs before teaching is an effective educational method.

For the task of correcting misconceptions, Piaget (1977) argued that cognitive conflicts improve misunderstandings by creating imbalances. Allowing people to experience mistakes in perception is one way to create cognitive conflict. Such experiences provide students an opportunity to reflect their visual perceptions critically and think about what is appropriate when they see things.

In this study, we tried an approach to overcome the misconception of mass conservation by students' critical rethinking of the perception of shape using the optical illusion. The formation of shape perception and illusion is considered the realm of science on forms. We intended to approach the educational problem of correcting misconceptions by applying science on form.

There is an optical illusion that aims at deceiving people's views. Ikeda (2009) stated that an illusion is a gap between the real world and the subjective visual world and that some illusions affect perception, cognition, and behavior. Hoefler (1994) affirmed that although vision is one of the senses on which a person depends most, "vision" and "reality" can be fairly different because the eye is gullible. Hoefler also confirmed that critical thinking is necessary for the accurate processing of information.

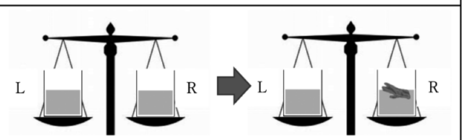
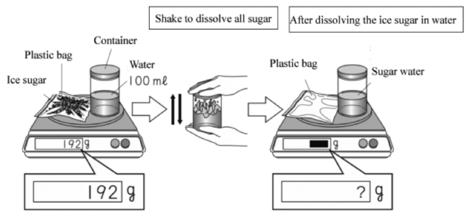
Thus, through experiences of visual illusions, the students may find that the first view they perceive might possibly be wrong and may find that there are multiple ways to see something. This activity is expected to induce critical thinking on the succeeding learning on such as the mass conservation in the change of form.

1.2 Purpose of the study

A hypothesis we test in this study is that the activities to experience cognitive conflicts based on the visual illusions will induce critical thinking on visual perception and then enables students to overcome misconception about the mass conservation through the process of shape changes. In this study, we introduce the activities on visual illusions to a usual lesson on "the weight of object". Then, we examine the effect of the activities on the scores of typical mass conservation problem. This work is an application of science on form to the design of teaching.

doi:10.5047/forma.2021.003

Table 1. Three questions of Mori and Kudo's evaluation test.

Index	Question	Choices	Figure
Q1	A cup with water and ice on the right and a cup with water on the left are balanced (same weight). What happens if the ice melt after a while?	1. The right is down. 2. The left is down 3. **(correct)** The balance does not tilt to either.	
Q2	The cup with water on the right and the cup with water on the left are balanced (same weight). What happens if a tree is floated on the cup on the right side?	1. **(correct)** The right is down. 2. The left is down. 3. The balance does not tilt to either.	
Q3	The container containing 100 ml of water and lump sugar, weighed 192 g. Next, the finely grounded sugar was poured into water, shaken well to dissolve everything, and weighed again.	What is the weight of the "?"? 1. It was lighter than 192 g. 2. (**correct**) 192 g had not changed. 3. It was heavier than 192g 4. It weighed only a plastic bag, a container and 100 ml of water.	

2. Method

2.1 Visual illusions as learning materials to induce critical thinking on the human senses

In this study, we include following four types of illusions as the visual illusion experiences.

2.1.1 "Geometrical-optical illusion": Visual image does not always correspond to actual shapes The geometrical-optical illusions induce students' cognitive conflicts between visual images of shapes and measured results that explain real geometrical shapes. The geometrical-optical illusions (GOI) we practiced were as follows.

GOI-(a): Ebbinghaus illusion: a central circle surrounded by large circles looks smaller than when surrounded by small circles (Roberts *et al.*, 2005).

GOI-(b): A modified version of the Ebbinghaus illusion: the size of the central circle is not equivalent. The students are convinced that the size is not visually determinable and that a measurement of sizes is necessary.

GOI-(c): Shepard tabletop: an optical illusion by R. N. Shepard (1990), where a pair of identical parallelograms set aside with a rotation of nearly 90 degrees looks like having different widths.

GOI-(d): Müller-Lyer illusion: two lines of the same length look to be of different lengths according to the direction of the arrows on both sides (Judd, 1905).

GOI-(e): Zöllner illusion: a series of parallel diagonal lines that cross with short repeated lines with the alternating horizontal and vertical directions look like a non-parallel alignment (Wallace and Crampin, 1969).

Observing these illusions, the teacher encouraged the students to measure the shapes and compare them to the images they see.

2.1.2 "Bottled water comparison": Quantity comparison of waters in different size bottles Two plastic bottles (polyethylene terephthalate bottle, PET bottle in abbreviation) of different shapes and capacities, 500 mL and 1000 mL. 400 g of water was put into a 1000 mL PET bottle, and 350 g of water was put into a 500 mL PET bottle, respectively. The teacher asked the students to compare the quantity of water in two bottles. The teacher intended to let the students being aware of the necessity of measuring weight when to compare the quantity of the objects of different shapes.

2.1.3 "Weight of transparent object": Weight of an object that transforms from visible to invisible The glass rod is visible in the air. The teacher showed that as he inserted the glass rod into a test tube filled with oil, it disappeared because the refractive indices of the glass and the oil are close. Thereafter, the teacher asked the students what happened in the weight of the test tube. The students found that the weight did not change despite the change of object visibility.

2.1.4 "Shape affects weight sensing": The object shape affects the sensing of its weight We prepared a set of 100 g weights made of iron, copper, and aluminum, instructed the students to hold it one by one with hand, with their eyes closed, and asked them to arrange objects in the order of weight. Thereafter, we asked the students hold the weights with their eyes open and rearrange them. Despite that they are the same weight, the lower the metal density

Table 2. Sessions on weight of object (WO).

WO steps	Title	Activities
Step 1	Measurements of various objects	Students hold various objects around them and compare their weights using the scale.
Step 2	Shape changes and weights	Students predict and measure whether the change of shape (or placement of parts) of the clay affects its weight.
Step 3	Shape changes and weights (discussions)	On the basis of experimental results, students obtain conclusions on the weight of the object when its shape change.
Step 4	Materials of the same volume	Students predict whether different types of the substances of the same volume will have distinct weights.
Step 5	Salt and sugar of the same volume	Students examine whether the same volume of salt and sugar weigh differently.
Step 6	Materials of the same volume (discussions)	Students understand that though the volumes are the same, the weight can differ depending on the material.

Table 3. Comparison of the lesson plans of the experiment and control groups.

Lesson	Experiment group lesson	Control group lesson
1	"Geometrical-optical illusion" from GOI-(a) to (e) "Bottled water comparison"	WO step 1
2	WO step 1, "Measurements of various objects"	WO step 2
3	"Weight of transparent object"	WO step 3
4	WO step 2, "Shape changes and weights"	WO step 4
5	WO step 3, "Shape changes and weights (discussion)"	WO step 5
6	"Shape affects weight sensing"	WO step 6, **Posttest**
7	WO step 4, "Materials of the same volume"	Geometrical-optical illusion
8	WO step 5, "Salt and sugar of the same volume"	Transparent rod illusion
9	WO step 6, "Materials of the same volume (discussions)", **Posttest**	Guess weights by hand

and the larger the size, the lighter it feels on one's hand. Through this experience, students find that the object shapes influence the way of feeling their weight.

2.2 Classroom practices and test

The classroom practices were conducted and the scores of pre- and post-test on typical mass conservation misconception questions were compared in three classes at two elementary schools in Tokyo from October to November 2019. The experimental group that practiced the optical illusion activities were class A of 29 students and class B of 35 students. The control group was class C of 33 students.

The pre- and post-evaluation tests were performed on the class to evaluate the effectiveness of the method. Table 1 shows three questions selected to detect students' misconceptions on mass and shapes. The questions were based on Mori (1973) and Kudo (2011). The questions Q1 and Q3 concern with the change or disappearance of the shapes of objects. It is known that many students tend to think that the materials lose their weight as they disappear. The question Q2 is compared with a similar question that a stone is located in the cup. Many students have a notion that when a tree float on the water it loses its weight. This is a misconception that an object loses weight as it floats, even though it maintains its shape.

Table 2 shows the activities of the weight of the object. The entire class consisted of nine-class times, where one class time is 45 min. The lesson plan of the "weight of object" was based on a science textbook of Tokyo Shoseki Co., Ltd. Table 3 shows the comparison of the lesson plans of the "weights of objects (WO)" for the experiment and control groups. The lessons consisted of the sessions on the visual illusions and those on the weight of the object (WO).

In the experimental class, the teacher conducted an evaluation posttest at the end of the entire lesson. The students of control classes learned optical illusions after the evaluation posttest, as supplemental lessons.

3. Results and Discussions

3.1 Observation of the experimental group

3.1.1 Geometrical-optical illusion lesson The tabletop illusion was surprising for many of the students. After the activities, the students wrote: "What you see with your eyes may be deceived." "If you do not measure it correctly, you will not know its true size."

In the activity of "Bottled water comparison", many students focused on the height of the liquid surface, but they realized that the difference in the bottom area made it impossible to make a judgment. After a while, the students began to compare weights with their hands. Gradually, more and more children began to realize that it would be better to compare the weight. Since they compared the weight with their hands, it was difficult to judge which one was heavier. Then, a student suggested using a scale. As a result of the measurement, the amount of water contained in the 1000 mL PET bottle was determined as larger than the 500 mL PET bottle.

Some of the students wrote the comments as, "I sometimes judge whether it is heavy or light by its shape, but

Table 4. Comparison of the proportions of correct answer of the pretest and posttest in the experimental and control groups.

Group	Pre- and posttest	Q1	Q2	Q3
Exp. Group (n = 64)	Pretest correct ans. rate	31.2%	68.7%	45.3%
	Posttest correct ans. rate	65.6%	84.4%	75.0%
	p-value on the difference between pre- and posttest	<0.001	0.010	<0.001
Ctrl. Group (n = 29)	Pretest correct ans. rate	44.8%	55.2%	44.8%
	Posttest correct ans. rate	44.8%	68.9%	62.1%
	p-value on the difference between pre- and posttest	1.000	0.191	0.093

sometimes I could not determine." and "I realized that the weight could judge the quantity of water." We believe that this lesson increased the children's awareness of measuring quantities correctly rather than judging by shapes.

3.1.2 Transparent rod illusion lesson In the third lesson, the students measured the weights of the oil-filled test tube and the glass rod. They put the glass rod into the test tube and weighed them. Students were surprised that the inserted portion of the glass rod became invisible. Nevertheless, many of them expected that there would be no loss of weight. Through this activity, the students seemed to accept it natural that the weight conserved even if the object became invisible. The observation suggested that, in this lesson, the students began to think of the visibility critically.

3.1.3 Fourth lesson Before measurements, many students predicted that the weight would remain the same regardless of the shape and orientation of the clay, citing as an example the weight of the glass that was invisible in the previous experiment of "Weight of transparent object". The reflection after the experiment showed that the students understood the mass conservation concept.

3.1.4 Sixth lesson, "Shape affects weight sensing" Most students seemed to feel that smaller weights were heavier on their hands. They were frightened when they heard that the weights were all 100 g and measured them. In the reflection after the experiment, the students wrote, "I cannot tell the weight from my hands." "I was deceived because I felt the big one was lighter." On the basis of this activity, the students developed the idea that they could determine object quantity by its weight measured accurately using a scale.

3.2 Comparison of pre- and posttest

Table 4 shows the rates of correct answers in the pre- and posttest of questions Q1, Q2 and Q3 shown in Table 1. The low scores appeared in the pretests of both the experimental and the control groups.

Improvements of the correct answer rates in the posttests were detected particularly in the experimental group. Table 4 also shows the p-values of the test of proportions of the correct answer rates. Considering Bonferroni correction (Dunn, 1961) on multiple comparisons with the total number of hypotheses $m = 3$, we tested the individual hypothesis at a significance level of $\alpha/m = 0.05/3 > 0.016$. Although the average correct answer rates of Q2 and Q3 increased in the posttests of the control group, these improvements were not statistically significant as seen in the p-values. These results of the control group suggest that usual classes of "weight of object" do not sufficiently affect students' notion of the weight of floating objects or the weights of melting and invisible objects.

The students of the experimental group had a chance to rethink critically their notion of weight that was based on the visible shapes and space-filling nature of an object. We found that the students discussed the restriction of visual perception using optical illusions as a thinking tool, before the lessons on the weight of objects. Also, recognition of the necessity of experimental measurements to ascertain the quantities of object was also essential to broaden the range of notions from the visible shapes to the weight. In this study, learning the visual illusions has raised the students' awareness of measuring physical quantities rather than relying on visual judgments.

4. Conclusion

In this study, we examined the effect of learning visual illusions on elementary students' overcoming of fundamental misconceptions on the mass conservation. The visual illusions we introduced to the students' learning were several types of optical illusions, a refraction effect, and an experiment that couples visual and haptic senses. The overcome of the misconceptions on the mass conservation was tested by the physics questions on the conservation of weight of objects in the process of melting, being transparent, and floating.

We found that the students faced a cognitive conflict on the visual illusions and recognized the necessity of the accurate measurements and the notion of weight to compare the quantity of objects. The students who learned the visual illusions before the classroom teaching on the usual "weight of objects" showed a significant improvement in the pretest and posttest sessions on the above physics questions. No significant improvement in the pre- and posttest was found in the control group without learning of the visual illusions.

Through the experiences to rethink critically of the visual perception, the students made it possible to break away from vague concept of weight that depends on vision and proceed to think weight beyond the division between visible and invisible. Introduction of visual illusion to the learning process may initiate a further application of science on form to the learning science. Contribution of the science on form to the learning science is expected.

Acknowledgments. The authors are grateful to Kou Sakuma, Mami Yamamoto, Ryohei Yamaguchi, and Misato Nomura for their supports and valuable discussions.

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